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AN EXPLORATORY ANALYSIS OF PROJECTION-STANDARD VARIABLES (SCREEN SIZE, IMAGE SIZE, AND IMAGE CONTRAST) IN TERMS OF THEIR EFFECTS ON THE SPEED AND ACCURACY OF DISCRIMINATION. FINAL REPORT.

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Although there has been previous research concerned with image size, brightness, and contrast in projection standards, the work has lacked careful conceptualization. In this study, size was measured in terms of the visual angle subtended by the material, brightness was stated in foot-lamberts, and contrast was defined as the ratio of the difference between the brightness of the background and the object to the brightness of the background. The effects of these independent variables were assessed by exposing three seventh graders (one boy and two girls) to all 125 experimental conditions in 20 half hour sessions. The subjects matched patterns on the upper half of a slide with one of two on the lower half. The criterion measures were reaction time and correctness of response. Brightness did not affect either of these criteria. However, reaction time tended to be shorter with an increase in visual angle and longer for minimal levels of contrast. Correct responses were largest for the middle value of visual angle and for higher levels of contrast. An inverse relationship between angle and contrast produced a maximum number of correct responses. Application of these results in the classroom is difficult in view of space and equipment limitations. (PM)

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AN EXPLORATORY ANALYSIS OF PROJECTION-STANDARD VARIABLES (SCREEN SIZE, IMAGE SIZE, AND IMAGE CONTRAST) IN TERMS OF THEIR EFFECTS ON THE SPEED AND ACCURACY OF DISCRIMINATION

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CHAPTER I

PROBLEM

One of the problems continually facing the audio-visual specialist concerns the physical aspects of the learning environment, particularly as it applies to projected materials. However, as Allen points out, "In general, the research on characteristics of the learning environment as it pertains to the use of AV materials has been inadequate (1:39)." While projection standards have been in existence for some time, these standards were developed before the advent of television, rear-projection devices, and the increased efficiency of present-day projectors and screens. Research involving proper utilization of television has recently cast doubts on the validity of accepted projection standards. (12:31) Gibson has observed that visual education authorities have recommended projection standards without experimental facts to support them (13:2).

Current Projection Standards

From time to time various organizations interested in the field of audio-visual have concerned themselves with minimum standards for projecting materials. While they have no doubt considered results from research, there is usually no reference to experimental findings in their statements of standards. Nevertheless, they have had considerable influence on what people in the field of audio-visual consider to be correct utilization practices. Their statements are frequently referred to as being based on fact, whereas they are apparently based largely on subjective evaluation.

One of the first organizations to establish projection standards was the Society of Motion Picture Engineers (now called the Society of Motion Picture and Television Engineers). In an issue of their Journal, they indicated that screen placement should be such that the members of an audience in an auditorium sit from between .87 and 6 screen widths from the projected image (20:45).

The Special Devices Training Center surveyed television utilization in Army training. Among their recommendations was one limiting the number of viewers of a television set to 20 (12:31).

The Department of Audiovisual Instruction of the National Education Association published a series of booklets dealing with audiovisual considerations in school plant planning. In the publication concerned with classroom planning, it is stated that a maximum of .1 footcandle of ambient illumination on the screen should be permitted for all types of projected materials. Further, it is said that such factors as type of material, equipment used, picture size, and other factors relating to the needs of the classroom should be considered. (15:8) Concerning screen placement, it is stated that the seating distance from projection screens should be from 2½ to 5 screen widths (15:21).

In an address before the Indiana State Conference on School Planning, Adrian TerLouw of Eastman Kodak stated the following:

> Although we can't assume that ideal viewing conditions can be achieved at all times in every classroom, some minimum standards have to be assured. Here are the ones on which the present discussion is based: . . .
>
> For every material viewed by projection -
>
> A screen image with a long dimension 1/6 the distance from screen to the farthest viewer. A value of 1/8 is tolerated.

> A screen image brightness produced by the projector at least twice as great as any bright area in the field of view. This must hold for every member of the class.
>
> A minimum screen brightness of 9 foot-lamberts for every member of the class, even those off to the side at the greatest viewing angle. A level of 20 foot-lamberts is preferred. (21:2)

He went on to say that full scale black and white or color materials require a non-image brightness to projector-image brightness ratio of at least 1 to 100. This requirement is reduced to 1 to 25 for color diagrams and continuous tone black and white in high key and to 1 to 5 for high contrast materials. (21:3) TerLouw also stipulated that visual acuity requires that a symbol to be discriminated must subtend nine minutes of visual arc (21:4). This is exemplified by a symbol of one inch viewed from a distance of 32 feet.

In Foundations for Effective Audio-Visual Projection, Eastman Kodak indicated the levels of ambient light to be expected under certain projection situations. The level of ambient light affects contrast, of course. A well-darkened room may be limited to .1 foot-lambert. On a sunny day, two layers of tan shades or tightly closed venetian blinds will reduce ambient light to 5 foot-lamberts. A normal classroom with unshaded windows and lit by the sky or with sun filtered by a single tan shade will contain 10 foot-lamberts of incident light. (8:14) It was also pointed out that too great a contrast may cause a dazzling effect (8:15).

The Educational Facilities Laboratory has published a study in the design of schools for educational television. Their recommended classroom layouts are predicated on viewing a receiver from within 12 screen widths. (9:32)

The American Standards Association has apparently adopted TerLouw's criteria for image contrast, saying that the contrast ratio should vary from 1:5 to 1:100 dependent upon the type of material being projected (2:10). They state that screen size should be one-sixth the distance to the farthest viewer. With certain slides having bold detail and contrast they would permit 1/10 screen widths (2:8).

Previous Research on Projection Conditions

One of the first research studies dealing with the effect of different projection conditions was conducted for the Army Air Force during World War II by James J. Gibson. He investigated the effect of various seating positions on scores made from a test presented on film. Tests were given to 1,104 subjects in groups of 200 subjects each. Tests were projected onto a seven foot screen. The experimenters found that there were no differences in the results obtained from subjects seated between 3 feet 9 inches and 56 feet from the screen (between .54 and 8 screen widths). The experimenters also found no difference in the results when projecting under .2 foot-candles of room illumination and "blackout" conditions. There was a difference at the five per cent level of significance in favor of .1 foot-candle over 1.4 foot-candles of room illumination. (13:45-58)

Lewis enlisted the aid of some 600 students in attempting to determine their likes and dislikes as to television viewing conditions. The subjects were asked to approach television and rear-projection devices until the image was clearly discernible and to continue toward the set until the picture lost its resolution. The subjects were then asked to fill out questionnaires regarding their reactions to the closest and farthest viewing conditions that were acceptable to them. Their responses indicated that the median closest position before the picture lost resolution was 6.75 screen widths and that the farthest acceptable distance was 22.88 screen widths. (17:196)

The Instructional Film Research Program under the direction of the Special Devices Center has also studied projection conditions. Ash and Jaspen studied the conditions under which a Telekit (a rear-projection device using film loops) could be used effectively. They considered the effects of viewing distance, viewing angle, room illumination, and the interaction of these variables. A film on the re-assembly of the 40mm breech block was used. Learning was measured by a performance test. They concluded that the optimum viewing area is contained within an arc 30° either side of the projection axis and twelve screen widths deep. Within this optimum area, performance was better when the film was viewed under daylight conditions. If the subject had been seated outside the optimum viewing area, his performance was better when the film had been viewed under blackout conditions. These results might have been due to the fact that reflected light from the screen is reduced when the viewing angle increases. Increasing the viewing angle had less of an effect than did increasing the viewing distance. The authors concluded that there was an interaction between the viewing angle and the amount of room illumination. (4)

Again using the Telekit and a film on the 40mm breech block, Ash and Jaspen manipulated the rate of development of the filmed concept, the extent of pupil participation, the amount of repetition, and the level of room illumination. Films embodying a slow rate of development and a fast rate of development were combined with various levels of participation, repetition, and room darkness. Learning was again measured by the ability of the student to re-assemble the breech block. Results indicated that projecting in a dark room yielded a significantly better score but that there was no interaction between room illumination and the other variables. (3)

There is an obvious relationship between the opacity of material to be projected and the amount of light striking the screen. The question then arises as to what is the effect of ambient light in relationship to the opacity of the materials being projected? This relationship was studied by Denno. The mean opacity of selected films in black and white and in color was determined. These films were presented to a jury of five teachers. The jury was to determine the minimum conditions under which films of varying opacity should be viewed as the ambient light conditions were changed. The jury indicated that an ambient light level not to exceed .15 foot-candles can be recommended for showing both black and white and color films. (7:5)

A need for more precise information than that available was felt by the Denver, Colorado, Public Schools. They were primarily interested in the optimum viewing distance from a television screen. Twenty-four classes of fourth graders with no experience in Spanish were chosen as subjects. They were presented three 15-minute lessons dealing with articles of clothing in Spanish. The learning tasks consisted of learning the names of the clothing and developing speaking skills with the vocabulary covered. Subjects were divided into three groups--those seated in the center of the room, those seated at the sides of the room, and those seated at the rear of the room. The rear positions were 24 to 28 feet from a 21 inch television set. The side positions were outside a 40° angle from the projection axis. Results in listening comprehension indicated no difference between subjects as a function of seating location. However, subjects occupying both the center and the back positions were significantly better at the speaking task than those seated at the sides. The difference between the scores obtained from subjects occupying the center and those occupying the back positions was not significant. (14:37)

In another investigation of the relationship between distance and distance, Westley and Severin collected data from 244 ninth grade algebra students. The distance of the student from a television screen was estimated by the classroom teacher and reported in five 10-foot intervals. Information regarding past achievement, expectation of achievement, social status, attitudes, and final achievement were used in analyzing the data. Subjects were allowed to retain their normal seating locations. Results indicated that the farther the student sat from the set, the greater his achievement. This conclusion was drawn from a small but statistically significant positive correlation of .204. (23:270)

Purpose of the Study

Two difficulties seem to develop when one analyzes projection standards. One is the wide discrepancy between stated standards and the results of research. Another problem is the lack of standardization and specificity in the variables examined, procedures used, and criterion measures.

In the first case, that of the discrepancy between standards and the results of research, the data speak for themselves. Figure 1 shows the range of standards for maximum viewing distance. It should be noted that published standards are considerably more conservative than the research results would dictate.

Research studies to date have involved various combinations of the following independent variables: (1) distance as measured in screen or image widths, (2) the extent of room illumination in foot-candles, (3) viewing angle, and (4) opacity of material being projected. The dependent variables have consisted of learning as measured by various criteria or judgment as to what seemed to result in pleasant viewing.

Several of the research reports indicated that while image width or screen width was important, its influence varied as a function of the grossness of the material being projected. This would imply that the critical variable regarding size is not screen width but the actual size of whatever is to be attended to on the screen.

The brightness and contrast of the projected image is a function of the total projection system. This system has many facets. Among these are (1) a specific projector, (2) a specific lamp, (3) a specific operating voltage, (4) a specific screen, (5) specific ambient light, and (6) specific material. In no study were all of these specified. In most cases these parameters were not mentioned.

For any kind of accumulation of knowledge through successive studies to take place, a careful specification of the values of variables

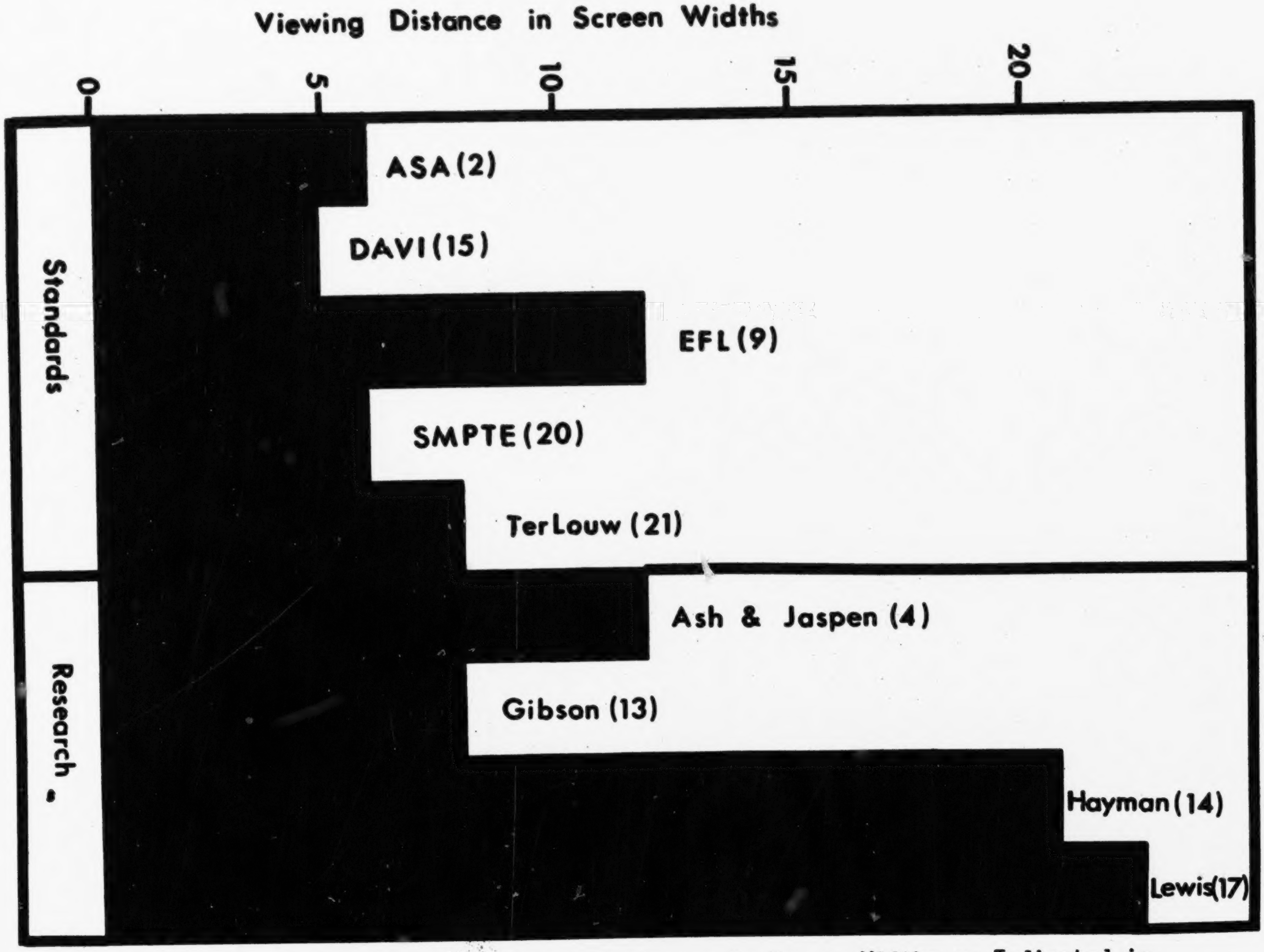

Figure 1. A Comparison of Maximum Viewing Distances in Screen Widths as Indicated in Published Standards and Research

is necessary. Within the framework of the previous paragraph, imagine the difficulty of simply defining, in operational terms, a projection lamp. Although researchers have been concerned with, in one form or another, the variables of image size, brightness, and contrast, careful specification of the values of these variables has been lacking.

If the effects of brightness, contrast, or size on visibility could be determined, it would then become the responsibility of the equipment manufacturers, material producers, and audio-visual specialists working together to determine the physical characteristics of their particular contributions to the learning environment. It is the purpose of the present study to evaluate projection conditions from the point of view of the effect on the viewer of image size, brightness, and contrast. Specifically, it attempts to determine the separate and joint effects of image size, brightness, and contrast on the visibility of material in terms both of the time required for discrimination and the accuracy of discrimination.

CHAPTER II

THEORETICAL BACKGROUND

According to Luckiesh, there are four factors that determine whether or not the material on this page is legible, They are as follows:

> (1) size of letters and their distinguishing details; (2) the contrast in brightness between "black" letters and their "white" background; (3) the actual brightness-level of the page as a whole and particularly the background; and (4) the time available for seeing. If this printed matter is to be readable, each of the four factors must have values above a certain minimum or what is termed threshold value. (19:56)

In other words, the visibility of an object is a function of size, brightness, contrast, and time. In the present study, size, brightness, and contrast were independent variables and are discussed immediately below. Time was a dependent variable and is discussed under the topic "Dependent Variables."

Independent Variables

Size. In the usual sense, size is considered an absolute. For example, if one applies a ruler to an object and states that it is an inch long, it will remain an inch long at any distance from the observer. However, when all frames of reference have been made unavailable to an observer--i.e., when such cues as those for distance and texture are eliminated--the perceived size of an object is a function of the physical size of the object and the distance at which the object is viewed. (19:87-90) Any combination of values of these variables may be defined for convenience in terms of a single quality--viz., visual angle or visual size, which is defined as ". . . the angle subtended by an object in the visual field at the nodal point of the eye (10:584)." Thus, a larger object relatively far from the eye may subtend the same visual angle as a smaller object relatively near to the eye. In this case, the perceived size of the two objects is identical. This relationship is shown in Figure 2. While S_1, S_2, and S_3 are obviously of different lengths, they subtend the same visual angle and are consequently of the same visual size. Visual size is computed by the following formula:

$$\tan \frac{a}{2} = \frac{S}{2d}$$

where a = visual size
S = size of object
d = distance of subject from object in the same measurement terms as the size of the object

There is a visual size of objects such that objects of a smaller visual size cannot be seen. When a given size is just "barely adequate" to elicit some specified response, this size is called threshold size. (10:554) Closely related to the concept of threshold size is the concept of visual acuity. Visual acuity is the ability of the individual to distinguish physically adjacent components of a visual target. The closeness of these components to each other is measured in terms of visual angle. (5:134) Visual acuity is defined as the reciprocal of the threshold size measured under certain standard conditions in terms of minutes of visual angle. If under these standard conditions, an individual is able to distinguish a physical separation of 1' of visual angle, his acuity is said to be a normal 1.00. (5:136)

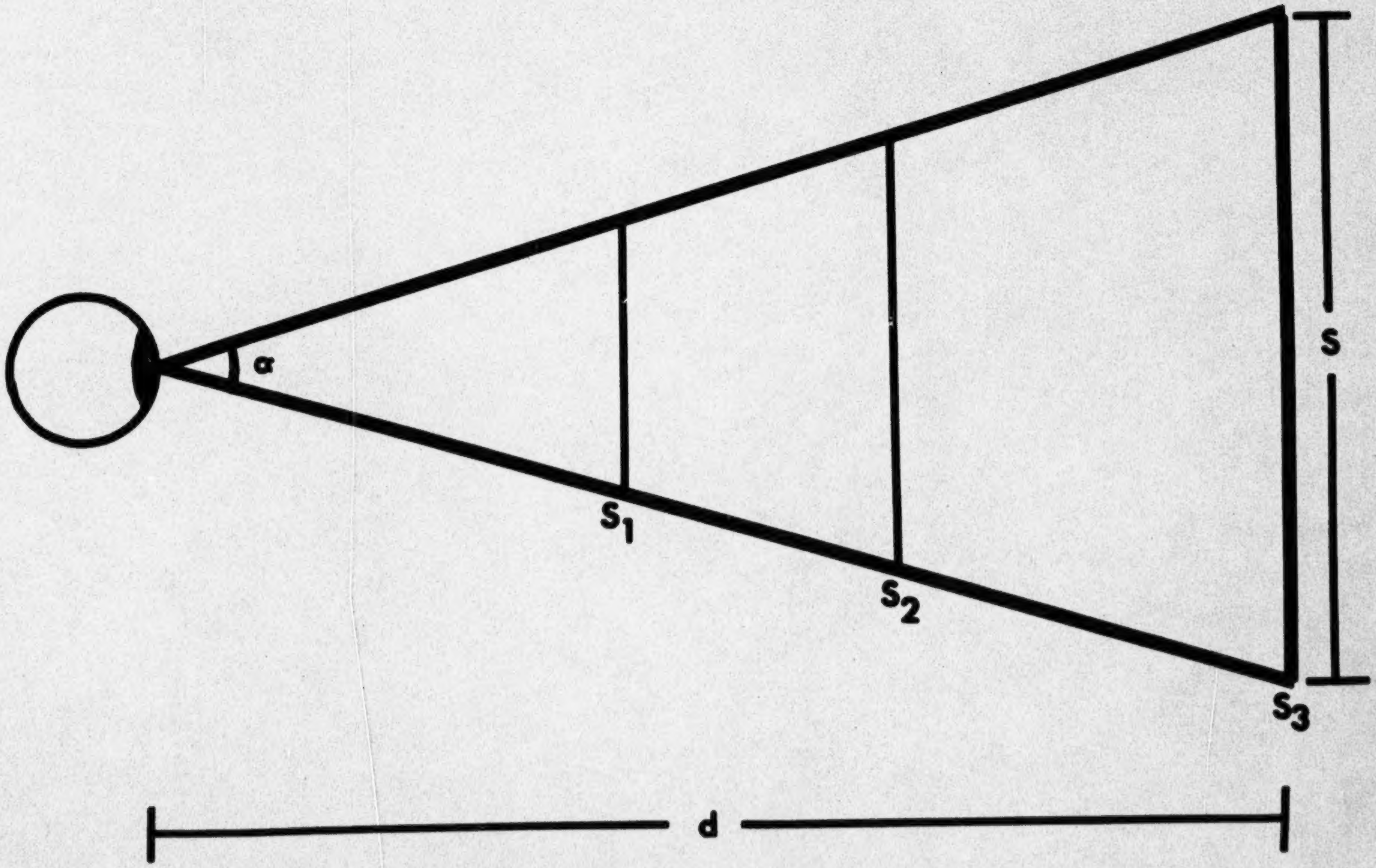

Figure 2. The Relationship Between Physical Size of an Object, the Distance from Which It Is Viewed, and the Visual Angle Subtended

During projection, the visual angle subtended by a letter on the screen is a function of both the actual size of the letter and its distance from the viewer. A letter whose height is equivalent to 1/20 screen widths and which is viewed from Gibson's recommended minimum viewing distance of .54 screen widths would subtend a visual angle of 5° 18'. (13:45-59) The same letter viewed from Lewis' maximum recommended viewing distance of 22.88 screen widths would subtend a visual angle of 7' (17:196). These visual angles are of the complete letter, not the detail necessary for letter recognition. The amount of visible detail necessary for letter recognition would be a function of the letter involved and the style of lettering used. But, regardless of these variables, for normal vision, detail would have to be larger than 1' to be above threshold when conditions of brightness and contrast are the standard ones used in testing visual acuity.

Brightness. Measurement of brightness depends upon the intended use of the measure. The output of a light source is usually measured in candlepower. When the output of this light source is directional, as in a projector, it is measured in lumens. If interest is in the amount of light striking a surface the measure is foot-candles. If one is interested in the amount of light reflected from an object, such as a projection screen, the measure is apparent foot-candles or foot-lamberts. For the purpose of this study, both light reflected from a front-projection screen and light transmitted through a rear-projection screen will be referred to in terms of foot-lamberts. When all of the variables affecting brightness in a projection situation are considered, the only measure affected by all of them is the amount of light reflected or transmitted toward the viewer from the screen.

One overhead projector manufacturer claims an output for his projector of 1800 lumens. If one filled a 70" by 70" screen, this projector would illuminate the screen with approximately 34 foot-candles of light. This figure is true under the simplifying assumption that there is no density whatsoever to the material being projected and that all light from the projector is hitting the screen. Front-projection type screens vary in reflectance on the projection axis from .86 to .6 of the light striking the screen. (16) Thus, these screens would reflect approximately 20 to 27 foot-lamberts of light from the overhead projector previously discussed. Most screens, however, lose their efficiency rapidly as one moves away from the projection axis. A glass beaded screen will lose two-thirds of its efficiency as the viewing angle is increased to 20°. This would cause the apparent light output from the above projector to be reduced to six to nine foot-lamberts.

Contrast. Contrast may be defined as follows: (19:108)

$$\text{Contrast} = \frac{\text{Brightness of Background} - \text{Brightness of Object}}{\text{Brightness of Background}}$$

This ratio is usually expressed as $\frac{\Delta I}{I}$, where Δ I is the difference in illumination between the background and the object, and I is the brightness of the background. (6:27)

In a projection situation, contrast is a function of all those variables affecting the brightness of an object being viewed and the brightness of the background. If a projector-screen-projection material combination is capable of producing a brightness of 20 foot-lamberts, and the object has a brightness of five foot-lamberts, the contrast would equal .75. If ambient light sufficient to reflect five foot-lamberts were added, contrast would be based on a background brightness of 25 foot-lamberts and an object brightness of 10 foot-lamberts. This would yield a contrast of .6. In actuality, the effect on contrast of ambient light would be less noticeable to a view on the projection axis and more noticeable as the viewing angle of the viewer increases. This is due to what is called gain in the screen. Since most screens are designed to be used in classrooms, the screen is engineered so that light is directed primarily back toward the projector, that is, on the projection axis. Consequently, a viewer located away from the projection axis would have less light reflected toward him than a viewer located on the projection axis. The former would be more affected by ambient light.

Interaction between size, brightness, and contrast. Considerable research has been done concerning the separate and joint effects of size, brightness, and contrast on visibility. However, this research has been concerned almost exclusively with threshold phenomena. Luckiesh has explored experimentally the quantitative relationships between size, brightness, contrast, and time, on the one hand, and on the other hand, threshold. (19) Bartley has summarized Luckiesh's findings as follows:

> . . . as target illumination varies from 1 to 100 foot-candles, threshold size varies from 15 to 5 minutes of arc for low contrasts in the target, and from 1.1 to .6 minute for high contrasts. . . . For targets with low contrasts and varying exposure time, from 7msec. to 300msec., threshold size varies from 20 to 13 minutes. . . . Within the same ranges of exposure time, but with high contrasts, threshold size varies from 1.3 to 1.1 minutes. . . . (5:137-138)

The investigations considered above dealt with threshold. Luckiesh has reported, however, that the performance of an undefined visual task which required 70 seconds when illuminated by three foot-candles of light, required 40 seconds when the illumination was increased to 50 foot-candles (19:36).

Dependent Variables

In a classroom, threshold levels would not seem to provide valid criteria for the design of materials and projection environments. A more appropriate criterion would seem to be the ease with which students are able to discriminate complex images on the screen. Therefore, in the present study, the concern is not with threshold, but rather with the effects of size, brightness, and contrast on discriminatory behavior. One convenient way of determining the ease with which discriminations are made is to measure discrimination time. Therefore, in the present study, the time required for discrimination was one of two dependent variables. The second dependent variable was the number of correct discriminatory responses.

Time. One response variable which has been found by experimental psychologists to be related to the difficulty of a task is the speed with which subjects are able to accomplish the task. This can be measured in two ways; namely, how much is done in an allotted time, and how quickly a task can be completed. The latter type of measurement is called *reaction time*. When the subject must discriminate stimuli before making a response, the measure is called a disjunctive reaction time. A disjunctive reaction has been classified as a b-reaction whenever the subject is required to make one response to one stimulus and a different response to a second stimulus. The present study involved a b-reaction.

Disjunctive reaction times vary in magnitude as a function of such variables as stimulus intensity, the similarity between stimuli, the number of alternative stimuli and responses available to the subject, the extent of practice, and the incentive provided the subject. Further, reaction time varies among individuals as well as in the same individual from trial to trial.

A reaction time situation consists of three consecutive periods, viz., the foreperiod, the reaction period, and the afterperiod. The foreperiod should be of such a length as to "allow the subject the proper time to establish a set toward making a response." The optimum foreperiod for a minimum reaction time should be approximately one second in duration. (25:8-42)

Correct response. Another response variable is the accuracy of the response. As the difficulty of a task increases, it is expected that the number of correct responses would decrease.

The Stimuli

Paul Fitts, while with the Laboratory of Aviation Psychology, Ohio State University, directed a series of investigations concerning the quantification of stimuli. Stimuli were specified in terms of information theory, i.e., in terms of the number of "bits" of information necessary to define the pattern. The investigators started out with a matrix in which any square could be randomly assigned as black or white with equal probability. However, in order to work with a more limited number of figures, the row or column of the matrix was used as the basic construction unit rather than each individual square. In addition to the amount of information necessary to define the stimulus pattern, Fitts was interested in the information theory concepts of noise and redundancy. Following various sampling rules, noise and redundancy were added to the patterns. The most familiar type of redundancy used was the symmetrical type, as exemplified by the appearance of milk bottles, trees, and many other familiar objects.

He tested the relationship between the information in the patterns and the responses of subjects in terms of paired associate learning, speed of locating figures from a heterogeneous sample, speed of naming patterns, and visual acuity. The major finding was that all tasks were affected in a similar manner by variations in the characteristics of the stimulus patterns as measured in terms of information theory. For purposes of the present study, stimuli were generated by sampling techniques used in the Fitts study. (11)

Summary

One of the necessary characteristics of the learning environment is that the material from which one is to learn be visible. Projection standards in the past have dealt with these requirements in terms of the physical characteristics of projection equipment and the projected materials rather than in terms of the visibility of the material on the screen. The present study dealt with the separate and joint effects of image size, image brightness, and image contrast on the ability of the viewer to discriminate between visual patterns.

Image size was measured in terms of the visual angle subtended by the material being viewed. Brightness was measured in terms of the foot-lamberts of brightness reflected or transmitted by the background of the screen toward the subject. Contrast was measured as the ratio of the difference in brightness between the background and the object to the brightness of the background. Criteria measures were, first, the length of time required to make a discriminatory response, i.e., reaction time, and, secondly, the number of correct responses made by the subject.

CHAPTER III

METHOD

The general characteristics of the procedures employed will now be described. Individual subjects were seated a specified distance from a rear-projection screen. They were presented several series of 2 x 2 slides, with the members of each series consisting of a particular value of size, of brightness, and of contrast. The image on the slide consisted of three patterns spaced equidistant from each other. The upper pattern was to be matched (identified as identical) with one of the two lower patterns, and a corresponding key, left or right, indicating the subject's choice, pressed as quickly as possible. The time required for the key-pressing response and the correctness of the response were recorded.

The Visual Patterns

Patterns were constructed on the basis of Fitts' studies (11). A 4 x 4 matrix was constructed, resulting in four columns and four rows. Starting at the bottom of the matrix, it is possible to construct figures so that each of the four columns could have any one of four heights. These figures could be further restricted so that the height of any one column would not be duplicated in any other column. On this basis all possible patterns were drawn, yielding 4! or 24 patterns. This population of 24 patterns was reduced by eliminating all matrices having a left hand column with a height of one or four, removing from consideration those patterns that seemed likely to be too easily recognized to produce differences as a function of the independent variables. Each of the 12 remaining patterns was rotated 90° clockwise and its mirror image produced, resulting in the 12 symmetrical patterns shown in Figure 3.

After being copied on high contrast film, the negatives were placed in a jig and re-copied in sets of three. The jig was designed to hold the patterns so that the center of each pattern was on a separate vertex of an isosceles triangle. The vertical distance between the upper pattern and the two lower patterns and the horizontal distance between the two lower patterns was equal to one-half the size of the individual patterns. Each possible combination of patterns was then photographed on high contrast film, resulting in a 2 x 2 positive slide as exemplified in Figure 4.

For each slide, the uppermost pattern was to be considered the standard. One of the lower patterns was identical with the upper pattern, while the remaining lower pattern consisted of any of the remaining eleven. This combination of patterns numbers 12 x 11 or 132. The fact that the identical lower pattern could occupy either the right or left hand position on the slide doubles the number of possible configurations to 264 slides. This number of combinations was numbered and a random sample of 500 with replacement was drawn.

Instrumentation

The equipment used in this study consisted of two slide projectors, a rear-projection screen, two response keys, response indication lights, and a timing device. The equipment was set up as indicated in Figure 5.

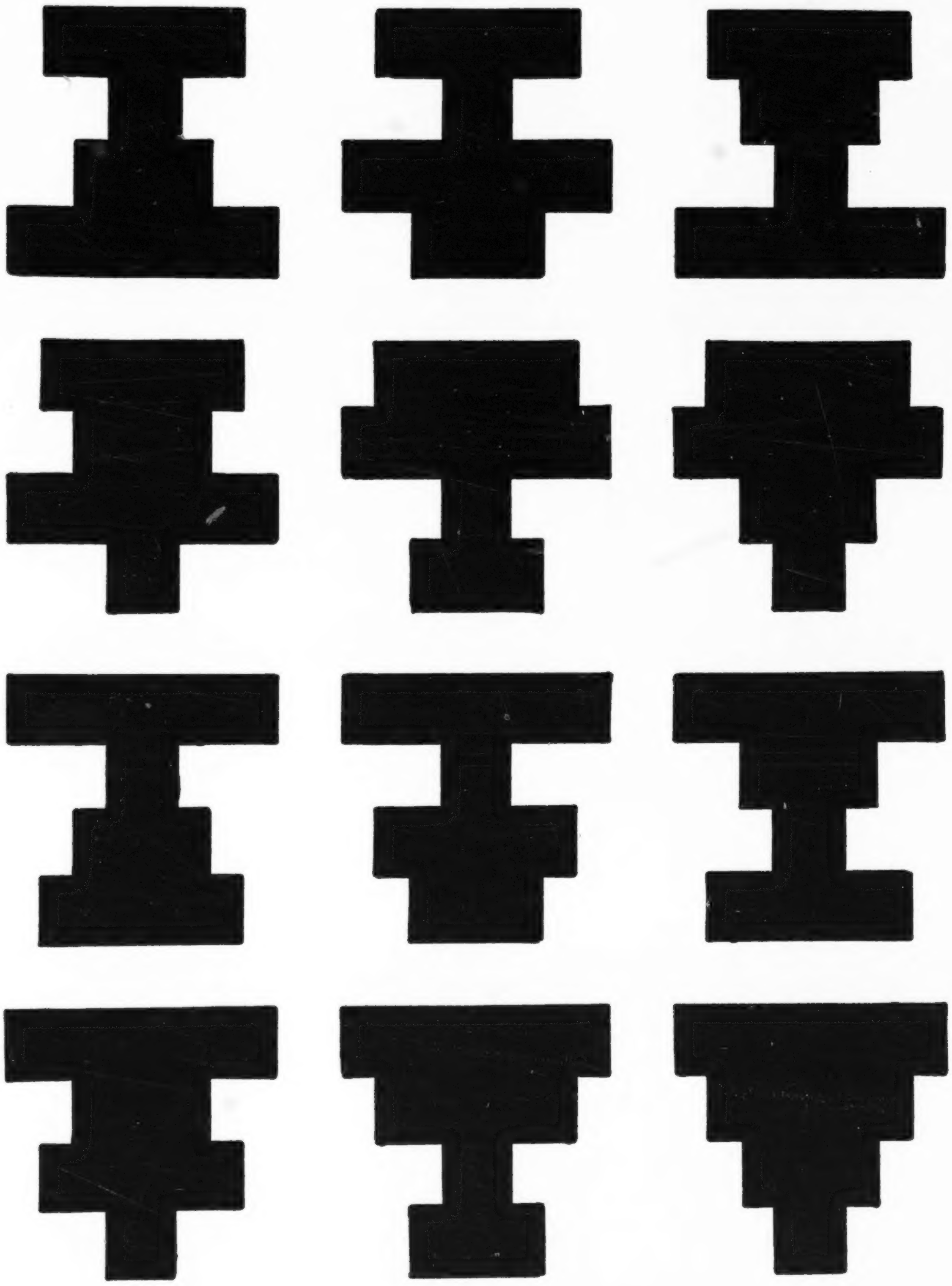

Figure 3. The Configuration of Patterns Used in the Present Study

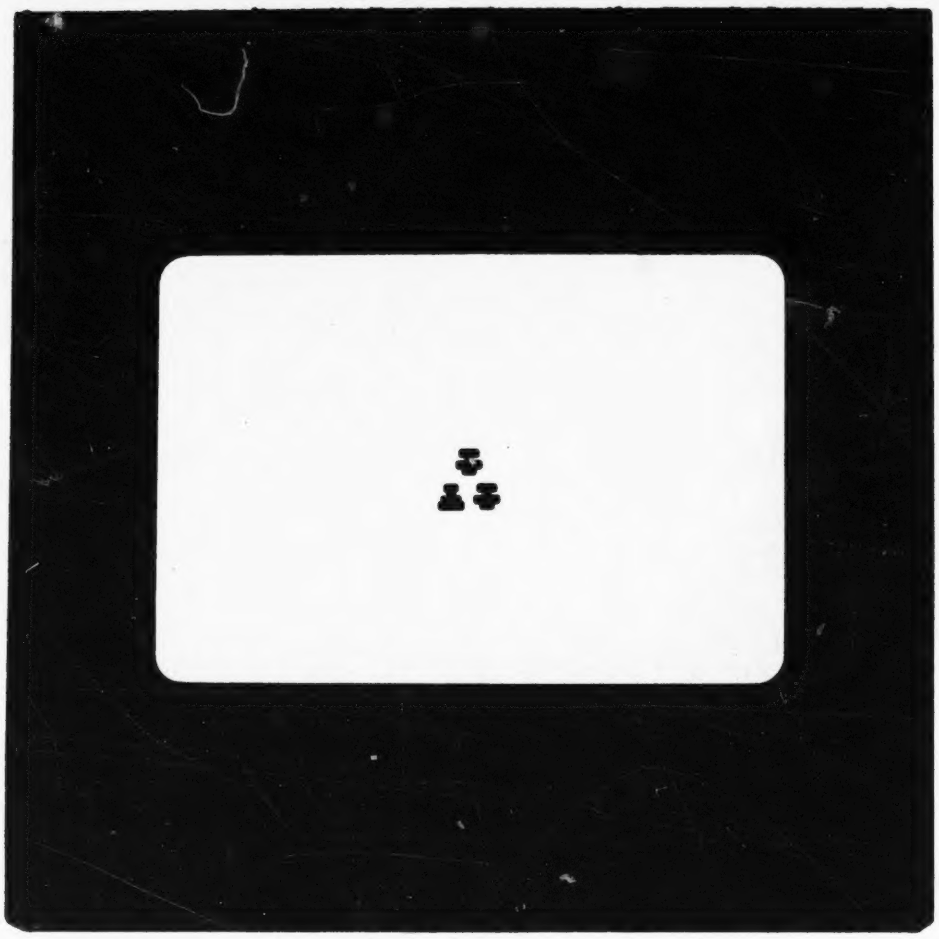

Figure 4. An Example of a 2 x 2 Slide of the Type Used in the Present Study as Stimulus Material

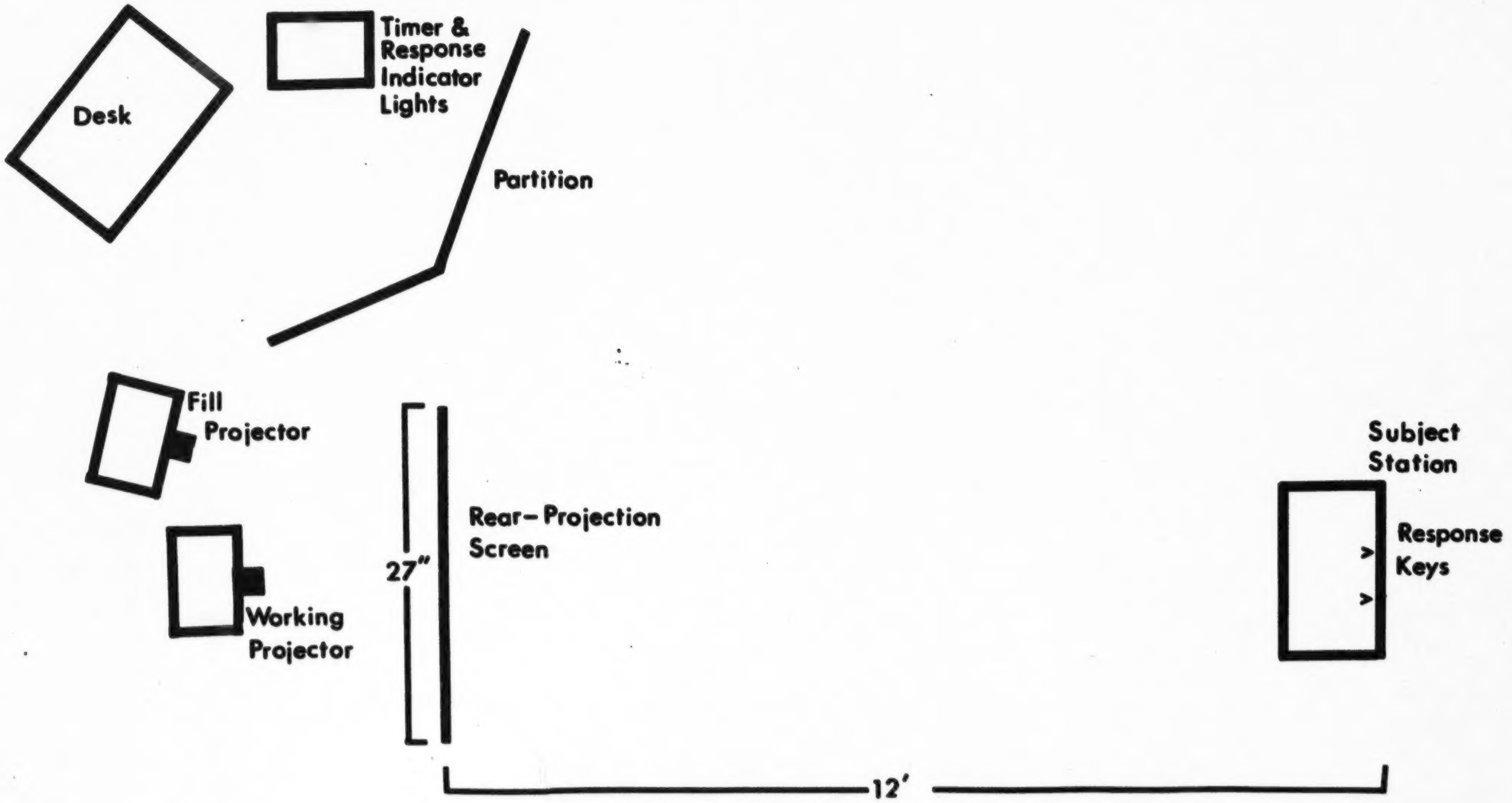
Desk
Timer &
Response
Indicator
Lights
Partition
Fill
Projector
Working
Projector
27"
Rear-Projection
Screen
Subject
Station
Response
Keys
12'

Figure 5. The Physical Arrangement of Equipment and Subject Utilized During the Experimental Sessions

Two 2 x 2 Eastman Kodak Cavalcade projectors were used. One was for projecting stimulus materials, and the combination of the two enabled contrast and brightness to be manipulated. The screen was a 27-inch Da-Tex rear-projection unit by Da-Lite having a resolving power of 14 lines per mm. (16:26). The response keys consisted of two telegraph keys mounted 12 inches apart on a one-inch by six-inch board. This board was not secured to the table at which the subjects sat, but its location in reference to the subject was periodically checked throughout an experimental session. Subject's choice times were measured with a Standard Electric 1/100 second timer. Latching relays were used to operate the timer. Two lamps indicated whether the subject made a right- or left-hand response.

The dependent variables' values were measured for each combination of values of the independent variables during a presentation of 20 slides. These slides were presented from the working projector as indicated in Figure 5, the projector having been set to advance automatically every four seconds. A snap-action switch mounted to close automatically on operation of the projector shutter was wired to the timer so that a momentary impulse through the switch closed a relay, starting the timer. This relay was a latching type so that the timer remained in operation until another impulse unlatched the relay. The unlatching impulse was generated by the closing of a telegraph key by the subject. Concurrent with this action, one of the lights on the face of the timer lit, indicating whether a right- or left-hand response had occurred. Four seconds from the starting of the timer another impulse was generated by the projector, turning out the indicator lights, changing slides, and re-starting the timer.

Size

The size of the image was controlled by simply moving the working projector closer or further from the screen. When a projector is moved closer to a screen, however, brightness normally increases. This increase in brightness was precluded by the addition of filters. The filters were produced by exposing sheet film in varying amounts and placing these sheets in a lantern slide holder mounted in front of the projection lens. Brightness measurements were made with a McBeth Illuminometer, the use of which will be explained later in this chapter.

Sizes were chosen on an a priori basis. The experimenter judged the minimum size that could be seen with difficulty and increased the image size in four steps to a maximum of one inch. The projected image was viewed from a distance of 12 feet. The actual physical sizes and visual size of each condition is shown in Table 1.

TABLE 1. THE RELATIONSHIP BETWEEN PHYSICAL SIZE AND VISUAL SIZE OF INDIVIDUAL PATTERNS AS VIEWED BY SUBJECTS AT A DISTANCE OF 12 FEET

Condition number	Physical size	Visual size
1	7/16 inch	10.44 minutes
2	8/16 inch	11.88 minutes
3	11/16 inch	16.32 minutes
4	14/16 inch	20.66 minutes
5	16/16 inch	23.84 minutes

Brightness and Contrast

Contrast ratios were given a priori values of .1, .3, .5, .7, and .9. The greatest brightness level of the background (1,024 foot-lamberts) was the maximum obtainable in achieving a .9 contrast ratio. Each brightness level of the background was set at one-fourth of the next higher level. Actual brightness levels of the background and the patterns to yield the various contrast ratios is shown in Table 2.

TABLE 2. THE CONDITIONS OF BRIGHTNESS AND CONTRAST RATIOS AND THEIR RELATIONSHIP TO EACH OTHER

Contrast ratio $\frac{\Delta I}{I}$	Brightness level of background in foot-lamberts				
	4.0	16.0	64.0	256.0	1,024.0
	Brightness level of patterns in foot-lamberts				
.1	3.6	14.4	57.6	230.4	921.6
.3	2.8	11.2	44.8	179.2	716.8
.5	2.0	8.0	32.0	128.0	512.0
.7	1.2	4.8	19.2	76.8	307.2
.9	.4	1.6	6.4	25.6	102.4

The brightness levels indicated in Table 2 were obtained by first illuminating the screen with the fill projector. Combinations of filters in the fill projector were determined that would yield the brightness level of the patterns. The working projector was then added to the fill projector and combinations of filters determined on the working projector that in combination with the fill projector would yield the proper illumination for the background.

All brightness levels were determined with a McBeth Illuminometer. This equipment permits brightness measurements through comparison with either a standardized, self-contained light source or with an external light source. Since in the experimental situation there was no way of controlling voltage fluctuations, lamp aging, etc., it was necessary to determine the light output of each projector as compared to the self-contained light source and from that point on to use the projectors themselves as external standards. Consequently, all readings of light intensity, with the exception of the original standardization, were taken with the unfiltered projector as the standard. Variations of illumination, due to voltage fluctuations and lamp aging, would cause some up-and-down fluctuation of brightness measurements but contrast would remain fairly constant. Periodic checks during experimentation verified some fluctuation in brightness measures but constancy of contrast.

Sampling

The 500 slides prepared as indicated on page 21 were ordered randomly and placed in 25 pre-numbered projection trays. From this point on, sampling for each presentation was from the population of the 25 trays, each containing 20 slides.

Each subject was presented 20 slides for each value of size in combination with each value of brightness and each value of contrast. The possible combinations of the values of the independent variables numbered 5^3 or 125. An independent random sample without replacement ordered the 125 values of the variables for presentation to each subject. For each combination of variables thus sampled, a tray was sampled with replacement for presentation. Table 3 shows the condition numbers assigned to each value of each of the three independent variables. The order of presentation of the various combinations of the value of the independent variables and the tray numbers assigned to each presentation are indicated in Appendix A.

TABLE 3. CONDITION NUMBERS ASSIGNED TO THE VALUES OF EACH OF THE INDEPENDENT VARIABLES

Condition number	Visual angle in minutes	Brightness in foot-lamberts	Contrast ratio
1	10.44	4	.1
2	11.88	16	.3
3	16.32	64	.5
4	20.66	256	.7
5	23.84	1,024	.9

The Subjects

One of the requirements considered necessary for each subject was normal vision. The subjects selected had had an eye examination within the past year and were able to show Vision Certificates indicating the following: (22)

1. 20/20 visual acuity or better in both eyes
2. Unrestricted binocular motility
3. Normal bifoveal fixation; passing standard stereo tests
4. No restrictions or scotomas in the visual field
5. Standard color vision.

Another requirement of the experimental situation was the extended experimental time required of each subject. Approximately 10 hours of contact time divided over 20 sessions was required of each subject in order that he be exposed to all 125 experimental conditions and thus act as his own control. This meant that subjects needed to be at an age level at which they could conveniently devote the time necessary for completion of the experiment. At the same time, coordination and a rather stable reaction time on the part of the subjects seemed desirable to increase the probability of response consistency. The experimenter judged that junior high school students could best meet these qualifications. Three seventh graders, one boy and two girls, were selected as subjects. These subjects met all the qualifications listed above.

It was assumed that the task of the subjects would tend to lose some of its novelty before the experimentation was completed. Consequently, each subject was promised the sum of $10.00 upon the completion of his contribution to the experiment.

Experimental Procedure

On each subject's first experimental session, he was seated at a table facing the rear-projection screen. After turning out the room lights and starting the working projector, the experimenter read the following:

> As you can see, there are three patterns on the screen. One of the two lower patterns is the same as the upper one. Which one is it? That's correct! We want to find out how quickly you are able to determine which one of the two lower patterns is the same as the upper one.
>
> You've also noticed the two telegraph keys in front of you. Instead of calling out which of the two lower patterns is the same as the upper one, I would like for you to press either the right or left key, depending on whether the right or the left pattern is the same. For example, if the right pattern of the lower two is like the upper one, press the right key. If the left pattern is the same, press the left key. Every few seconds a new set of patterns will appear on the screen. Just as soon as you are able to determine which of the lower patterns is like the top one, you should press the corresponding key as quickly as you can.
>
> Now, let's see how you hold the keys. First, place your wrists on the table in front of the keys. Then place the first two fingers of each hand on the corresponding key. This is the position you should hold during the actual time we are seeing slides. It is not necessary for you to press the keys hard. Just with whatever pressure you feel comfortable. Keep your wrists on the table and your fingers on the keys at all times. You will have ample opportunity to rest. Why don't you take that position and practice for a few seconds so that you will get the feel of the keys.
>
> Please don't press the key until you are sure which pattern is the same. I think you will have the best results and see the difference more quickly if you look at a point in the center of the patterns rather than at each pattern directly. Try looking about here. Do you understand so far?
>
> You will see sets of patterns in series of twenty. I will ask if you are ready before starting each series of twenty. At that time you should place your hands in the correct position for pressing the keys. Before each slide there will be two clicks from the projector about one second before the patterns appear on the screen, and except for the first slide, the screen will go dark while the slides are changing. This will warn you to be ready to press one of the keys.
>
> After we have started a series of patterns, please do not talk. Each series will take only a minute or so, so that any questions you may have should be held until the series of

twenty is complete. I will tell you when the series is complete so that you may stretch or relax for a bit.

The most important thing is for you to concentrate as hard as you can on the patterns and to press the correct key as quickly as you can. Be sure to press only one key each time, never both.

Let's review. When I call ready, you should place your wrists on the table in front of the keys and the first two fingers of each hand on the keys. This position you should hold throughout a series of twenty slides. The projector will make two clicks. This will warn you that a set of three patterns is about to come on the screen. During the period between clicks and the pattern on the screen you should get ready to press one of the keys. When the patterns appear, you should determine which of the lower two patterns is like the upper one and press the correct key as quickly as possible. Press only one key. I will tell you when the series is complete so that you can relax.

Let's try some patterns and see how we do. Do you have any questions? Ready?

The subject was then presented a series of slides and corrections were made of any violation of the procedures. Questions were answered and further examples given until the experimenter was sure that the subject knew the mechanics of his task. The foreperiod was approximately one second in duration.

Five trays of practice slides had been prepared. The subject was now given 20 minutes of practice using the practice slides. No further slides were shown during this first session.

At the beginning of each succeeding experimental session, the procedure was reviewed and one series of the practice slides used as a warm up with the experimental condition being arbitrary. Each session was limited to one-half hour in length. During each session it was normal to complete from seven to ten series of slides, depending upon the time required to make the physical changes required to establish the experimental conditions. Each series of slides required approximately 80 seconds to complete. The actual set-up time between series, requiring a possible shift in working projector location and filter changes in both projectors, sometimes took up to two minutes. This time was used by the subject for relaxation and rest. He was allowed to close his eyes or move about if he felt it necessary.

From the experimenter's point of view, once a series of slides had started, the operation became automatic; the slides were advanced by the projector at four-second intervals. The projector started the clock, and the subject stopped the clock by pressing one of the response keys. Time for a series of 20 slides accumulated on the clock and was recorded at the end of the series. A record was kept of whether a right or left response was given. This was the only record maintained with respect to the individual slides. The recording sheets were prepared prior to the experiment and indicated the subject number, experimental conditions, and slide tray to be used for each series.

CHAPTER IV

RESULTS

In the case of each of the five values of each of the three independent variables, a mean reaction time was obtained by adding the reaction time both over 20 slides at each combination of values of the other two independent variables and also over the three subjects. Thus, each of these values was based upon 20 x 5 x 5 x 3 = 1,500 observations. Similar means were obtained in the case of the number of correct responses with the exception that the means were with respect to the entire set of 20 slides used for each combination of values of the independent variables. The 15 means thus obtained for each of the two dependent variables are shown in Table 4. Mean values for each subject separately are shown in Appendix B.

An examination of the means shown in Table 4 does not lead to a simple description of the nature of the results with respect to either of the dependent variables. Therefore, the statistical significance of the various experimental effects will be discussed at this point. Tests of significance of main effects and especially of simple effects makes possible a description of the results that is meaningful.

It will be recalled that each subject was observed under all combinations of values of the three independent variables. Thus, the analysis of variance used is appropriate to what may be called a "Treatments x Treatments x Treatments x Subjects" design, which is a simple extension of a design described by Lindquist (18:237). The results of this analysis are presented in Table 5. A critical region corresponding to the .05 level of significance was adopted. Asterisked values of F in the table are statistically significant.

TABLE 4. MEAN REACTION TIME AND MEAN NUMBER OF CORRECT RESPONSES FOR EACH VALUE OF VISUAL ANGLE, BRIGHTNESS, AND CONTRAST

Independent variables	Dependent variables	
	Mean reaction time in seconds	Mean number of correct responses
Visual angle in minutes		
10.44	1.09	16.48
11.88	1.15	17.08
16.32	.97	17.96
20.66	.95	17.87
23.84	.94	17.69
Brightness in foot-lamberts		
4	1.05	17.20
16	1.13	17.13
64	.97	17.72
256	.97	17.31
1,024	.97	17.72
Contrast $\left(\frac{\Delta I}{I}\right)$		
.1	1.19	15.45
.3	.99	17.47
.5	.92	17.95
.7	.96	18.11
.9	1.04	18.11
Grand mean	1.02	17.42

TABLE 5. DEGREES OF FREEDOM, SUMS OF SQUARES, MEAN SQUARES, AND F-RATIOS OF MAIN EFFECTS AND INTERACTIONS OF VISUAL ANGLE, BRIGHTNESS, AND CONTRAST FOR REACTION TIMES AND NUMBER OF CORRECT RESPONSES

Source of variation	df	Reaction time			Number of correct responses		
		SS	MS	F	SS	MS	F
Visual angle (A)	4	2.55	.64	3.56*	117.37	29.34	5.75*
Brightness (B)	4	1.57	.39	2.17	24.25	6.06	1.19
Contrast (C)	4	3.17	.79	4.39*	381.77	95.44	18.71*
Subjects (S)	2	3.87	1.93		214.90	107.45	
AS	8	1.42	.18		44.28	5.53	
BS	8	1.51	.19		32.60	4.07	
CS	8	1.51	.19		45.48	5.68	
Pooled	24		.18			5.10	
AB	16	1.69	.10	.53	35.88	2.24	.91
AC	16	2.57	.16	.84	118.23	7.39	2.99*
BC	16	3.06	.19	1.00	70.42	4.40	1.78
ABS	32	7.29	.23		92.23	2.88	
ACS	32	5.51	.17		83.48	2.61	
BCS	32	5.74	.18		61.70	1.93	
Pooled	96		.19			2.47	
ABC	64	12.47	.19	1.12	208.52	3.26	1.33
ABCS	128	22.02	.17		314.01	2.45	
Total	374	75.95			1,845.10		

Error Terms

The error term for each experimental effect was obtained by pooling the interaction of this effect with subjects with all other interactions of the same order involving subjects. The decision to use a pooled error term was based on Hartley's test of homogeneity of variance (24:92-96).

As indicated in Table 6, for each order of interaction, there was no evidence of heterogeneity of variance. Table 7 shows the error terms used in the analysis.

The results for reaction time and for correct responses will be discussed separately. In each case, the main effects and simple effects will be considered first, followed by a consideration of the interactions.

Reaction Time

As shown in Table 5, the main effects of visual angle and contrast were statistically significant while the main effect of brightness was not. Considering first the variable of visual angle, it can be seen in Table 4 that although in general reaction time was shorter with an increase in visual angle, there was one exception. Reaction time was shorter at a visual angle of 10.44' than it was at a visual angle of 11.88'. To determine the statistical reliability of this inversion as well as to determine in general just what means were statistically different from others, a Newman-Keuls test was performed (24:80-89). Results of this test are presented in Table 8.

TABLE 6. HARTLEY'S TEST OF HOMOGENEITY ON THE EQUIVALENT LEVEL INTERACTIONS INVOLVING SUBJECTS

Source	MS	df	F_{max}
Reaction time			
BS (Highest) AS (Lowest)	.19 .18	3,8	1.06
ABS (Highest) ACS (Lowest)	.23 .17	3,32	1.35
Correct responses			
CS (Highest) BS (Lowest)	5.68 4.07	3,8	1.40
ABS (Highest) BCS (Lowest)	2.88 1.93	3,32	1.49

TABLE 7. ERROR TERMS APPLIED TO STATISTICAL ANALYSIS OF DATA ON REACTION TIMES AND CORRECT RESPONSES

Applied to	Source	df	MS_{error}	
			Reaction time	Correct responses
Main effect	$\frac{(SS_{AS} + SS_{BS} + SS_{CS})}{(df_{AS} + df_{BS} + df_{CS})}$	24	.18	5.10
First order interaction	$\frac{(SS_{ABS} + SS_{ACS} + SS_{BCS})}{(df_{ABS} + df_{ACS} + df_{BCS})}$	96	.19	2.47
Second order interaction	ABCS	128	.17	2.45

TABLE 8. NEWMAN-KEULS TEST OF INDIVIDUAL DIFFERENCES BETWEEN RANKED PAIRS OF REACTION TIME MEANS FOR VISUAL ANGLE

Rank (R)	1	2	3	4	5
Treatments in order of mean reaction time	23.84'	20.66'	16.32'	10.44'	11.88'
Mean reaction time in seconds	.94	.95	.97	1.09	1.15
Differences between pairs of means	23.84'	20.66'	16.32'	10.44'	11.88'
23.84'	-	.01	.03	.15	.21*
20.66'		-	.02	.14	.20*
16.32'			-	.12	.18*
10.44'				-	.06
Truncated range r $(\|R_j - R_i\| + 1)$		2	3	4	5
$q_{.95}(r,24)$		2.92	3.53	3.90	4.17
$q_{.95}(r,24)/\sqrt{MS_{error}/n}$ (Difference required for significance)		.14	.17	.19	.20

Results indicate that the reaction time to a visual angle of 11.88' was significantly longer than the reaction time to the three visual angles larger than this value. Reaction time did not increase in monotonic fashion as visual angle decreased, although tests of statistical significance did not support a non-monotonic relation.

The overall relationship between contrast and reaction time is even less clear than the relationship between visual angle and reaction time. The two largest means occur at the extreme values of contrast. Thus, it seemed that no meaningful statement could be made without an examination of the simple effects. The results of a Newman-Keuls test of the statistical significance of these effects are shown in Table 9.

TABLE 9. NEWMAN-KEULS TEST OF INDIVIDUAL DIFFERENCES BETWEEN RANKED PAIRS OF REACTION TIME MEANS FOR CONTRAST

Rank (R)	1	2	3	4	5
Treatments in order of mean reaction time	.5	.7	.3	.9	.1
Mean reaction time in seconds	.92	.96	.99	1.04	1.19
Differences between pairs of means	.5	.7	.3	.9	.1
.5	-	.04	.07	.12	.27*
.7		-	.03	.08	.23*
.3			-	.05	.20*
.9				-	.15*
Truncated range r ($\lvert R_j - R_i \rvert + 1$)		2	3	4	5
$q_{.95}(r,24)$		2.92	3.53	3.90	4.17
$q_{.95}(r,24)\sqrt{MS_{error}/n}$ (Difference required for significance)		.14	.17	.19	.20

Results indicate that the reaction time to the lowest contrast used, namely .1, was longer than to all other values of the independent variable. Evidence would therefore indicate that at minimal values of contrast, reaction time is increased. The increased reaction time found at the larger values of contrast (.9) did not prove statistically different from the three intermediate values used in the study.

The overall test of the effect of brightness on reaction time provided no evidence that reaction time was affected by brightness. There also were no significant interactions between the three independent variables with respect to reaction time. Results of these overall tests are shown in Table 5.

Correct Responses

As shown in Table 5, the main effects of visual angle and contrast with respect to the number of correct responses were statistically significant while the main effect of brightness was not. Also there was a significant interaction between visual angle and contrast.

In the case of visual angle, an examination of the means in Table 4 indicates that the largest number of correct responses was obtained at the middle value of visual angle, namely 16.32'. The least number of correct responses was obtained when visual angle was the smallest, 10.44'. The Newman-Kuels test was applied to these data in order to determine the statistical significance of the difference between the means. The result of this test is shown in Table 10.

As in the case of the relationship between visual angle and reaction time, the relationship between visual angle and the number of correct responses is not entirely clear. The correct responses obtained from a visual angle of 10.44' were significantly different from the three

TABLE 10. NEWMAN-KEULS TEST OF INDIVIDUAL DIFFERENCES BETWEEN RANKED PAIRS OF CORRECT RESPONSE MEANS FOR VISUAL ANGLE

Rank (R)	1	2	3	4	5
Treatments in order of mean number of correct responses	10.44'	11.88'	23.84'	20.66'	16.32'
Mean number of correct responses	16.48	17.08	17.69	17.87	17.96
Differences between pairs of means	10.44'	11.88'	23.84'	20.66'	16.32'
10.44'	-	.60	1.21*	1.39*	1.48*
11.88'		-	.61	.79	.88
23.84'			-	.18	.27
20.66'				-	.09
Truncated range r ($\lvert R_j - R_i \rvert + 1$)		2	3	4	5
$q_{.95}(r,24)$		2.92	3.53	3.90	4.17
$q_{.95}(r,24)\sqrt{MS_{error}/n}$ (Difference required for significance)		.14	.17	.19	.20

largest values of visual angle. The number of correct responses did not vary in monotonic fashion as visual angle increased, although tests of statistical significance did not support a non-monotonic relation.

The effect of contrast on the number of correct responses produced a monotonic relation. As shown in Table 4, the least number of correct responses was obtained at the minimum value of contrast. As contrast increased, so did the number of correct responses. This increase, however, did not continue at values of contrast above .7. To determine the statistical significance of differences between means, the Newman-Kuels test was again applied, the results of which are shown in Table 11.

TABLE 11. NEWMAN-KEULS TEST OF INDIVIDUAL DIFFERENCES BETWEEN RANKED PAIRS OF CORRECT RESPONSE MEANS FOR CONTRAST

Rank (R)	1	2	3	4	5
Treatments in order of mean number of correct responses	.1	.3	.5	.7	.9
Mean number of correct responses	15.45	17.47	17.95	18.11	18.11
Differences between pairs of means	.1	.3	.5	.7	.9
.1	-	2.02*	2.40*	2.56*	2.56*
.3		-	.38	.54	.54
.5			-	.16	.16
.7				-	.00
Truncated range r ($\lvert R_j - R_i \rvert + 1$)		2	3	4	5
$q_{.95}(r,24)$		2.92	3.53	3.90	4.17
$q_{.95}(r,24)\sqrt{MS_{error}/n}$ (Difference required for significance)		.14	.17	.19	.20

This analysis indicates a statistically significant difference only between the number of correct responses obtained when contrast had a value of .1 and all other values of contrast.

In the present study, one interaction proved significant; namely, that between visual angle and contrast in the case of number of correct responses. Table 12 shows the cell means of correct responses for the various combinations of values for visual angle and contrast. An examination of the table yields the fact that for the lower values of contrast, visual angle has a considerable effect on the number of correct responses. Also, for the lower values of visual angle, contrast has a similar effect. As the values of each of the two independent variables increase, the relative effect of the other on the number of correct responses diminishes. This relationship is also shown in the isometric drawing in Figure 6.

TABLE 12. CORRECT RESPONSE MEANS AS A FUNCTION OF VISUAL ANGLE AND CONTRAST

Visual angle in minutes	Contrast ($\frac{\Delta I}{I}$)				
	.1	.3	.5	.7	.9
10.44	13.20^{25}	16.87^{20}	$17.33^{16.5}$	16.80^{21}	$18.20^{7.5}$
11.88	14.53^{24}	17.27^{18}	17.73^{13}	$18.53^{3.5}$	$17.33^{16.5}$
16.32	15.93^{23}	17.60^{14}	19.00^{1}	18.80^{2}	18.46^{5}
20.66	16.53^{22}	$17.80^{11.5}$	18.13^{9}	$18.53^{3.5}$	18.33^{6}
23.84	17.07^{19}	$17.80^{11.5}$	17.53^{15}	17.87^{10}	$18.20^{7.5}$

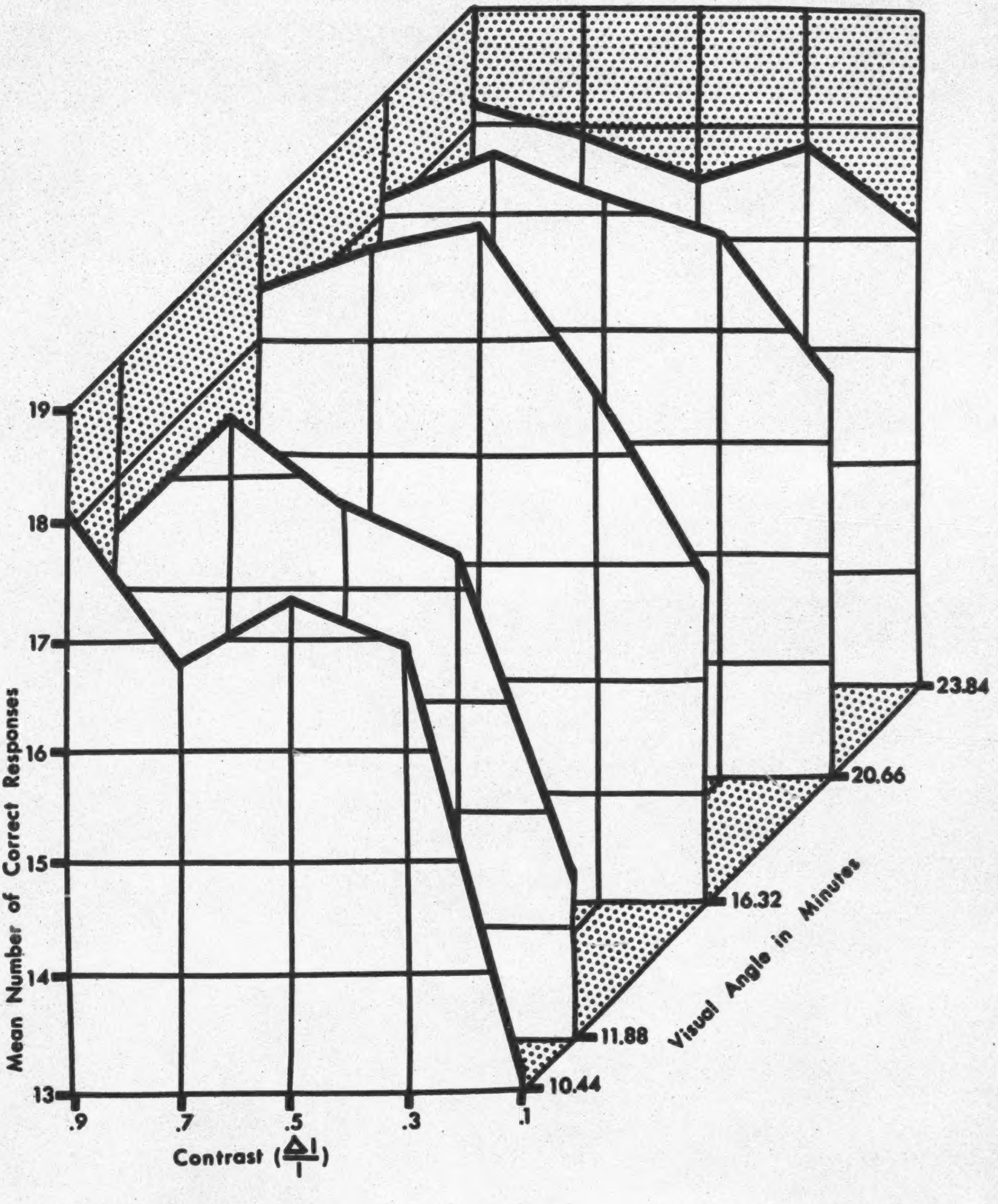

Figure 6. The Interaction of Visual Angle and Contrast with the Number of Correct Responses as the Dependent Variable

In interpreting Figure 6, the reader should remember that it is a three dimensional graph, and as such, only those points in a common plane may be compared. The mere height of a point on the drawing is of no significance unless it is compared with its own base. With this in mind, the following relationships can be drawn. In general, visual angle effects the number of correct responses. This effect is tempered, however, by the contrast of the material being viewed. The maximum effect of visual angle is obtained when the contrast is at a minimum with the effect apparently reducing to zero at maximum contrast. This relationship is indicated by the decreasing slope of correct responses from the front to the rear of the graph as contrast increases.

The same type of relationship exists when contrast is considered. The slope from right to left is quite steep when visual angle is small. It decreases, however, as visual angle increases.

Summary

Fairly consistent results indicate the effect of visual angle and contrast on both reaction time and the number of correct responses. Individual differences between treatment means indicate, however, that this effect lies primarily with the minimum values of visual angle and contrast used in this study. In general, values of visual angle of 11.88' and below and values of contrast of .1 showed significantly longer reaction times and lower number of correct responses than other values of visual angle and contrast. Brightness had no effect on either of the two dependent variables.

The only significant interaction occurred between visual angle and contrast in the case of number of correct responses. The nature of the interaction was such that visual angle and contrast each had its maximum effect on the number of correct responses when the value of the other independent variable was low.

CHAPTER V

DISCUSSION AND CONCLUSIONS

In order to equate the patterns used in the present study with visual tasks of students in a normal classroom situation, certain assumptions are necessary. They are as follows:

1. All students in a classroom have visual capabilities approximating normality.
2. The range of contrast used in the study approximates that found in a normal classroom situation.
3. The visual task is similar in complexity to that found in a normal classroom situation.

These assumptions, of course, cannot be totally accepted. It is a well-known fact that all students do not have normal vision. This is particularly true in the lower grades where, if normality is measured by adult standards, very few students have 20/20 vision.

As for contrast, it was found in the present study that contrast affects the visibility of a target. And while the contrast ratios used in the present study were well defined, there exists no definition of contrast in a normal classroom situation.

As to the complexity of the visual task, no attempt has been made to equate the stimulus material used in this study to the lettering occurring in visual materials. It is obvious that the style of letter presented may have a great effect on its visibility.

If one does accept the above assumptions, however, certain recommendations are possible. These recommendations are discussed under the headings corresponding to the independent variables.

Image Size

It will be recalled that the subjects were able to perform better when the patterns subtended a visual angle of 16.32' than they were when the visual angle was 11.88' in the case of reaction time or 10.44' in the case of the number of correct responses. An increase above 16.32' to 23.84' had no apparent effect on performance.

Since the two dependent variables yielded slightly different results, recommendations will be based on the more conservative of the results. It is therefore recommended that materials should not subtend a visual angle of 11.88' or smaller, and that for optimum performance the visual angle should equal or exceed 16.32'.

In the usual parlance of the audio-visual field, size is referred to in terms of proportional parts of screen widths. Letter height, however, is more closely related to proportional parts of screen height. If the screen (image) is of a square format, no difficulty is caused by this discrepancy. If, however, the image is of a rectangular format, the height of the image should be the referent for determining letter size. Figure 7 shows the recommended size of print in proportional parts of screen height for different viewing distances in screen heights.

In using the figure, it should be assumed that the screen is filled. Any combination of screen heights and letter height intersecting below the diagonal lines will allow the letter to subtend a visual angle exceeding 16.32'. Since the experiment did not involve visual angles between 16.32' and 11.88', this area is questionable. However, if requirements are such that smaller lettering must be used, the area between the two diagonal lines may be appropriate provided contrast is high.

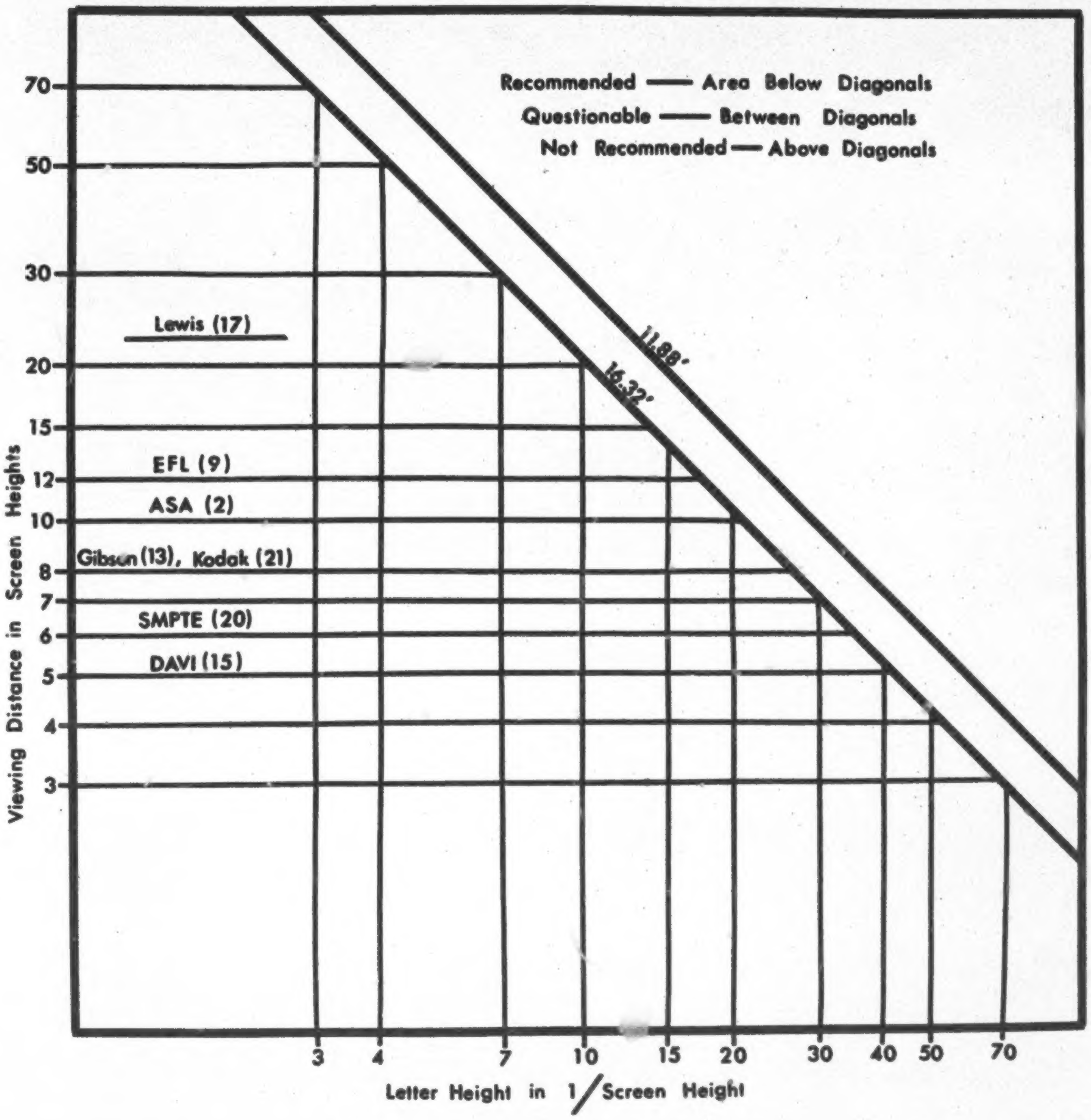

Figure 7. Recommendations for the Size of Printed Material Expressed in Proportions of Screen Heights for Different Viewing Distances Expressed in Screen Heights Along with Selected Current Projection Standards and Research Findings

The figure may also be used to compute the proportional size of lettering for artwork from which to make visual materials. For example, if material is being viewed from within 10 screen widths, the minimum letter size should be 1/20th of the screen height. This same proportion applies to artwork from which materials are being prepared. If the artwork were 10 inches high, lettering should be 1/2 inch in height.

The figure also makes it possible for the reader to supplement the recommendations of previous projection standards and research findings with recommendations of the present study. For example, if one follows the viewing distance standards of DAVI of five screen widths, the minimum lettering size should be 1/40th screen heights.

Contrast and Brightness

While neither reaction time nor the number of correct responses varied as a function of brightness, it must be remembered that contrast is a function of brightness. Varying contrast did cause an effect on both reaction time and the number of correct responses. A contrast of .3 and above yielded a significantly better response than a contrast of .1.

From a practical point of view, the only way one can manipulate contrast is by varying the brightness of various aspects of the environment. The contrast capable of being generated by a given projector and screen will be changed radically by varying the brightness of ambient light. Unfortunately, the manipulation of light to develop a specific contrast ratio is a much more difficult task than the manipulation of visual size. In a normal school situation, the type, brand, and efficiency of projectors change periodically. The control of ambient light is expensive. All parameters such as these affect the contrast of material being shown. The problem is further complicated by the fact that the measurements determining contrast must be taken from the screen under actual projection conditions. These problems and many more make it difficult to apply in the practical situation the recommendations found concerning contrast.

While no significant differences were apparent between the middle values of contrast and the upper values of contrast, the reaction times, in terms of absolute values, increased when contrast was high. As a matter of fact, reaction time was at a minimum at a contrast ratio of .5. It is possible that an undesirable effect was beginning to occur at the higher contrast ratios.

Interaction Between Visual Angle and Contrast

From a practical point of view, one of the most difficult and necessary problems to solve in the classroom is the interaction between visual size and contrast. It is not infrequent that projected materials are used in the classroom where neither the size nor contrast of the materials can be controlled or varied.

It will be recalled that separately the minimum values of either variable resulted in significantly reduced visibility. However, as long as either of the variables had a sufficiently high value, visibility was not reduced. With visual angle at a minimum, a contrast of .5 or higher greatly improved performance. With contrast at a minimum, visual angle increased to a value of 23.84' before the effect of contrast was minimized.

It follows, then, that if a room cannot be sufficiently darkened, materials must be increased in size for them to be adequately visible. Conversely, if materials are of a minimum size, contrast must be relatively high for adequate visibility to occur.

Future Research

Recommendations for future research involve not only additional questions that need to be answered, but also involve the way in which the questions in the present study were approached. First to be covered will be a way in which the present questions could be re-examined, and secondly, additional questions needing research.

Evaluation of the present study. Several points are evident on analysis of data from the present study. First, while the two dependent variables gave fairly consistent results, one discrepancy occurred; namely, that of the interaction between visual angle and contrast. This interaction was not evident in terms of reaction time but was evident in terms of the number of correct responses. Where no discrepancy occurred, i.e., in the main effects, the F-ratios were generally higher for the number of correct responses than for reaction time. This implies, at least on an ad hoc basis, that reaction time was a less sensitive dependent variable than the number of correct responses.

Secondly, there were several inversions in the functional relations examined. These inversions are evident in the case of both dependent variables. Although none of these inversions was statistically reliable, it is possible that they might be if a larger number of subjects was observed. In spite of the fact that each data point was based upon 1,500 observations, the particular random assignments of stimulus patterns to experimental conditions could, for example, have led to misleading results.

It will be recalled that the effects of three independent variables; namely, visual angle, brightness, and contrast, were measured on each of two dependent variables, reaction time and the number of correct responses. Since time is a variable affecting visibility, it must be considered. It does not, however, have to be considered as a dependent variable but rather can be controlled by means of a tachistoscope, for example, and treated as an independent variable.

Two basic problems emerged regarding the stimuli as used in the present study. The patterns were extremely time consuming and expensive to create. Further, since the population of stimuli was so great, it was virtually impossible to build into the slides themselves the values of the independent variables. This meant that instrumentation had to be changed continually to affect the different combinations of values of the independent variables.

If a target such as the Landolt C had been used, only four possible stimulus configurations would have existed, making more feasible the building into the slides themselves the various combinations of the values of the independent variables. The Landolt C has another advantage in that it is a standard measure of visual acuity. If the gap in the C is visible under standard lighting conditions when it subtends a visual angle of 1', vision is considered normal. The use of this type of stimuli would allow much greater generalization and consequently would add more to the existing knowledge of proper use of projected materials.

Additional research. Many variables affecting the performance of a student while viewing projected materials were not considered. Among additional research questions that may be of interest are the following:

1. The effect of fatigue
2. The effect of a negative rather than positive image
3. The effect of a colored background
4. The effect of color on color
5. The effect of age
6. The effect of various anomalies of vision
7. The effect of establishing set in various manners
8. The effect of various letters and letter styles
9. The effect of resolution of the projection system.

In addition to the above research questions, a considerable amount of development is needed within the audio-visual field. One of the basic needs within the audio-visual industry is a standardization of specifications concerning various aspects of projection systems so that appropriate combinations of equipment, room facilities, and materials may be formed which will meet the requirements of the students as to visibility. In other words, information is needed which will allow a projection system to be treated as a system rather than as individual items of equipment and materials.

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APPENDIX

Appendix A

Order of Presentation, Conditions Assigned Each Presentation, and Slide Trays Assigned to Each Condition

Presentation number	Subject 1				Subject 2				Subject 3			
	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray
000	4	2	2	00	2	2	1	15	5	5	1	12
001	5	3	3	00	1	3	1	22	4	2	5	15
002	2	1	5	10	1	5	1	20	3	2	2	01
003	2	4	5	06	4	5	1	19	2	3	2	08
004	1	3	3	12	5	4	4	17	1	5	1	19
005	1	2	1	11	1	1	3	21	5	1	5	08
006	3	3	3	14	3	3	1	10	4	4	2	22
007	5	3	1	05	5	2	5	22	2	5	3	15
008	2	4	2	15	1	3	4	00	2	3	5	07
009	4	3	1	18	4	2	1	23	2	1	4	14
010	5	2	2	12	3	2	2	17	2	1	3	05
011	4	3	2	10	4	5	2	03	3	2	4	05
012	4	4	1	07	3	5	5	04	4	4	4	18
013	1	4	5	05	3	5	3	22	4	5	4	08
014	5	3	5	21	4	4	2	10	5	2	2	06
015	2	2	4	07	4	1	4	22	3	2	3	09
016	5	5	4	17	3	3	4	18	4	1	5	19
017	1	5	1	22	2	1	1	17	2	1	2	09
018	2	5	1	05	2	2	2	24	2	4	4	06
019	4	3	4	22	3	2	1	14	3	1	1	17
020	1	3	5	13	3	5	2	08	3	2	5	14
021	3	2	1	10	3	1	4	09	3	4	5	03
022	2	1	2	22	5	5	4	15	4	5	3	04
023	5	1	5	11	1	3	3	04	5	3	2	23
024	2	1	3	20	1	2	2	05	4	3	1	14
025	1	2	4	09	2	3	1	06	1	5	4	20
026	2	5	4	19	3	4	3	12	2	3	4	03
027	5	5	5	14	5	1	3	03	3	3	3	18
028	5	5	1	02	3	4	2	06	4	4	1	02
029	5	5	2	07	3	5	4	16	4	2	2	17

Appendix A (Continued)

Presentation number	Subject 1				Subject 2				Subject 3			
	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray
030	2	2	3	02	4	1	3	08	5	3	5	00
031	4	4	2	03	5	2	4	08	3	5	4	19
032	3	1	4	05	2	2	3	18	5	3	4	11
033	4	5	2	09	2	4	1	08	5	5	2	02
034	5	2	4	13	2	1	4	07	1	1	3	02
035	1	4	2	05	1	1	1	24	1	4	5	11
036	4	5	5	08	4	3	3	17	4	1	1	06
037	4	1	3	13	2	2	5	10	5	5	3	22
038	3	1	5	19	2	5	1	02	3	1	2	11
039	4	1	4	15	4	5	5	05	5	5	4	24
040	4	4	4	14	4	4	5	18	2	1	1	01
041	4	1	2	06	3	2	3	20	1	4	2	15
042	3	3	2	17	5	1	4	06	4	2	4	00
043	5	1	1	08	1	5	5	17	4	1	4	21
044	1	1	5	17	5	5	1	18	2	4	2	21
045	4	2	1	19	5	1	5	12	4	2	3	11
046	3	5	3	15	5	4	2	07	5	2	3	13
047	3	5	1	06	4	2	2	13	1	3	2	19
048	1	2	3	16	3	1	2	02	2	5	1	11
049	4	3	5	20	2	3	4	19	1	3	4	13
050	2	4	4	12	2	5	5	13	3	2	1	20
051	3	3	5	07	1	1	2	18	3	4	4	10
052	5	2	1	24	1	1	5	15	2	2	3	12
053	1	4	1	21	2	1	5	14	5	4	3	20
054	1	3	1	15	5	1	1	05	1	1	2	12
055	2	1	1	23	5	3	4	02	5	1	2	03
056	3	3	4	02	3	1	5	23	5	2	4	16
057	5	4	3	10	3	1	1	13	3	5	2	16
058	3	5	5	12	5	5	5	24	2	5	4	23
059	4	5	4	11	5	5	3	10	1	2	2	10
060	5	1	4	01	3	3	3	24	5	5	5	18
061	4	1	1	12	4	1	5	16	1	1	5	24
062	1	4	3	19	4	3	2	14	2	5	2	00
063	3	4	5	16	1	5	4	14	4	3	2	20
064	2	5	5	00	2	2	4	21	1	5	3	14

Appendix A (Continued)

Presentation number	Subject 1				Subject 2				Subject 3			
	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray
065	1	5	5	23	5	3	5	01	3	1	4	15
066	5	3	2	19	5	3	3	13	2	3	1	04
067	5	4	2	18	3	4	4	05	2	4	1	16
068	4	2	4	21	1	4	4	13	2	4	5	13
069	3	1	3	21	2	4	3	16	1	4	4	17
070	2	2	1	17	1	3	5	08	4	1	3	16
071	4	5	1	16	3	2	4	11	5	3	1	15
072	1	5	4	10	2	1	2	20	3	4	2	04
073	3	2	2	23	2	3	2	12	5	2	5	21
074	3	4	1	09	1	2	5	06	2	2	5	22
075	2	3	4	16	1	2	1	12	1	2	1	08
076	3	1	2	05	5	4	3	14	4	4	3	24
077	3	4	2	01	1	5	3	07	2	2	1	24
078	3	4	4	08	2	5	2	01	4	5	1	03
079	3	2	4	20	3	4	5	19	1	3	1	21
080	1	5	2	20	2	4	4	04	3	3	5	02
081	5	4	1	20	1	5	2	11	5	4	4	01
082	5	4	4	23	5	5	2	21	4	5	5	10
083	1	3	2	24	5	1	2	19	1	2	4	07
084	1	1	2	02	2	5	3	09	2	3	3	10
085	5	1	2	16	4	2	3	02	5	1	3	07
086	5	2	5	21	3	3	2	15	3	1	3	00
087	1	5	3	18	1	4	2	09	1	1	4	22
088	2	2	2	14	2	3	5	03	1	5	5	01
089	2	1	4	18	5	3	2	23	3	4	1	07
090	3	3	1	03	1	4	5	02	4	1	2	13
091	2	3	2	11	4	3	1	07	1	1	1	18
092	4	2	5	05	1	1	4	10	5	3	3	17
093	1	3	4	06	3	4	1	03	2	2	4	02
094	4	5	3	01	1	4	3	23	4	5	2	07
095	3	5	2	13	4	3	4	20	2	4	3	19
096	5	2	3	06	4	5	4	12	4	3	4	09
097	2	5	2	21	3	5	1	00	3	5	5	06
098	1	1	4	03	4	4	1	21	1	5	2	05
099	2	2	5	03	3	2	5	07	5	1	4	04

Appendix A (Continued)

Presentation number	Subject 1				Subject 2				Subject 3			
	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray	Size	Brightness	Contrast	Tray
100	1	1	1	14	2	5	4	23	1	2	3	03
101	2	3	5	09	4	2	4	01	2	1	5	20
102	4	2	3	05	2	1	3	11	4	3	5	05
103	5	4	5	22	2	3	3	05	3	3	1	22
104	2	3	3	08	5	2	2	04	3	3	4	12
105	2	3	1	01	3	1	3	01	5	1	1	10
106	4	4	3	17	4	1	1	04	5	4	1	05
107	5	1	3	09	4	4	4	24	5	2	1	19
108	1	2	5	01	5	4	5	20	1	3	5	16
109	5	5	3	03	5	2	3	00	5	4	2	14
110	2	5	3	05	2	4	5	00	2	5	5	17
111	1	4	4	00	5	2	1	16	1	3	3	06
112	4	1	5	24	1	3	2	16	5	4	5	09
113	3	2	3	22	1	2	3	19	1	4	1	00
114	4	4	5	02	4	4	3	15	1	2	5	04
115	4	3	3	23	4	2	5	09	2	2	2	18
116	1	2	2	08	1	4	1	01	4	2	1	23
117	3	2	5	18	4	1	2	00	3	4	3	08
118	1	1	3	07	4	3	5	11	1	4	3	23
119	5	3	4	05	5	4	1	11	4	4	5	12
120	2	4	1	13	3	3	5	21	4	3	3	01
121	2	4	3	24	2	4	2	22	3	1	5	23
122	3	4	3	11	4	5	3	06	3	3	2	24
123	3	5	4	24	1	2	4	03	3	5	3	21
124	3	1	1	00	5	3	1	09	3	5	1	13

Appendix B

Number of Correct Responses and Average Time Per Response in Seconds for Each Experimental Condition by Subject

Minutes visual angle	Brightness	Contrast	Subject 1		Subject 2		Subject 3	
			Number correct responses	Average time per response	Number correct responses	Average time per response	Number correct responses	Average time per response
10.44	4	.1	12	1.44	19	0.77	09	1.51
10.44	4	.3	17	1.29	19	0.88	12	1.28
10.44	4	.5	18	1.02	17	0.98	15	1.32
10.44	4	.7	18	1.14	15	0.76	14	1.38
10.44	4	.9	19	1.14	18	0.82	18	1.46
10.44	16	.1	19	1.20	14	1.38	08	1.78
10.44	16	.3	18	1.27	14	0.99	12	1.63
10.44	16	.5	20	1.09	15	0.69	16	1.27
10.44	16	.7	18	1.02	16	0.80	15	1.26
10.44	16	.9	19	0.98	16	0.77	18	1.01
10.44	64	.1	16	1.18	17	1.28	09	1.55
10.44	64	.3	17	1.28	18	0.80	15	1.13
10.44	64	.5	17	0.94	17	0.80	18	0.95
10.44	64	.7	20	1.13	19	0.73	17	1.16
10.44	64	.9	18	1.09	18	0.78	17	1.09
10.44	256	.1	15	1.14	10	1.56	07	1.57
10.44	256	.3	19	0.99	19	0.88	17	0.98
10.44	256	.5	20	1.00	15	0.72	19	0.87
10.44	256	.7	20	0.93	16	0.77	14	0.96
10.44	256	.9	19	0.86	19	0.76	15	1.06
10.44	1,024	.1	13	1.54	16	1.37	14	1.70
10.44	1,024	.3	19	1.14	19	0.82	18	0.97
10.44	1,024	.5	18	1.12	19	0.72	16	1.13
10.44	1,024	.7	18	1.03	16	0.74	16	1.25
10.44	1,024	.9	20	0.96	20	0.80	19	0.99
11.88	4	.1	16	1.46	15	1.17	15	1.29
11.88	4	.3	18	1.06	18	0.83	11	1.88
11.88	4	.5	18	1.18	18	0.74	17	1.64
11.88	4	.7	20	1.34	20	0.76	15	1.55
11.88	4	.9	17	1.09	17	0.76	19	0.91

Appendix B (Continued)

Minutes visual angle	Brightness	Contrast	Subject 1		Subject 2		Subject 3	
			Number correct responses	Average time per response	Number correct responses	Average time per response	Number correct responses	Average time per response
11.88	16	.1	16	1.34	15	1.28	11	1.38
11.88	16	.3	20	1.07	18	0.87	16	0.99
11.88	16	.5	20	0.96	17	0.79	15	0.90
11.88	16	.7	18	0.89	18	0.72	17	0.92
11.88	16	.9	18	1.11	14	0.84	18	0.90
11.88	64	.1	16	1.25	14	1.27	15	1.39
11.88	64	.3	19	1.18	17	0.76	19	1.20
11.88	64	.5	19	1.04	16	0.67	14	0.86
11.88	64	.7	20	0.93	20	0.71	19	0.78
11.88	64	.9	17	1.14	17	0.74	20	1.26
11.88	256	.1	13	1.15	12	1.42	10	1.47
11.88	256	.3	17	0.98	16	0.76	20	1.11
11.88	256	.5	18	0.95	18	0.73	19	0.80
11.88	256	.7	20	0.97	20	0.72	17	1.27
11.88	256	.9	19	0.95	16	0.69	17	1.25
11.88	1,024	.1	18	1.25	16	1.09	16	1.25
11.88	1,024	.3	19	0.90	13	0.88	18	1.28
11.88	1,024	.5	20	0.94	20	0.81	17	1.66
11.88	1,024	.7	19	1.18	16	0.68	19	1.16
11.88	1,024	.9	19	0.91	14	0.70	18	0.82
16.32	4	.1	19	1.38	15	1.09	14	1.63
16.32	4	.3	18	1.09	17	0.70	14	0.88
16.32	4	.5	19	1.01	19	0.71	19	1.05
16.32	4	.7	20	1.13	18	0.77	18	1.16
16.32	4	.9	18	1.11	16	0.73	19	0.87
16.32	16	.1	13	1.09	15	0.94	12	1.24
16.32	16	.3	19	1.06	18	0.84	18	1.23
16.32	16	.5	19	1.02	20	0.84	18	1.26
16.32	16	.7	20	0.91	18	0.73	17	1.37
16.32	16	.9	17	0.91	18	0.61	18	1.29

Appendix B (Continued)

Minutes visual angle	Brightness	Contrast	Subject 1		Subject 2		Subject 3	
			Number correct responses	Average time per response	Number correct responses	Average time per response	Number correct responses	Average time per response
16.32	64	.1	16	1.15	16	1.12	15	1.07
16.32	64	.3	18	1.10	19	0.70	15	0.93
16.32	64	.5	20	1.04	19	0.73	18	1.19
16.32	64	.7	20	0.92	19	0.77	19	0.81
16.32	64	.9	20	0.92	18	0.70	20	0.85
16.32	256	.1	17	1.48	19	1.11	18	0.98
16.32	256	.3	19	0.97	18	0.76	17	0.79
16.32	256	.5	20	0.90	19	0.71	18	0.75
16.32	256	.7	19	1.03	19	0.68	18	1.13
16.32	256	.9	19	1.05	20	0.77	18	1.33
16.32	1,024	.1	20	1.02	16	0.79	14	0.99
16.32	1,024	.3	16	1.11	18	0.80	20	1.22
16.32	1,024	.5	20	0.93	19	0.79	18	0.75
16.32	1,024	.7	19	0.91	19	0.76	19	0.84
16.32	1,024	.9	19	0.91	19	0.77	18	0.90
20.66	4	.1	17	1.07	16	0.80	15	1.28
20.66	4	.3	16	1.02	17	0.73	15	0.97
20.66	4	.5	18	0.90	17	0.71	18	0.95
20.66	4	.7	20	0.94	18	0.73	18	0.95
20.66	4	.9	20	0.99	19	0.77	20	1.28
20.66	16	.1	19	1.06	18	0.99	14	1.24
20.66	16	.3	19	0.90	19	0.76	18	1.06
20.66	16	.5	19	1.21	18	0.64	20	1.01
20.66	16	.7	20	1.01	18	0.64	17	0.91
20.66	16	.9	20	1.16	18	0.73	10	1.27
20.66	64	.1	16	1.19	19	0.79	17	1.16
20.66	64	.3	19	1.02	20	0.70	19	1.21
20.66	64	.5	20	1.00	18	0.73	18	0.84
20.66	64	.7	19	1.07	18	0.67	17	0.92
20.66	64	.9	19	1.09	18	0.68	19	0.82

Appendix B (Continued)

Minutes visual angle	Brightness	Contrast	Subject 1		Subject 2		Subject 3	
			Number correct responses	Average time per response	Number correct responses	Average time per response	Number correct responses	Average time per response
20.66	256	.1	16	1.04	14	1.24	13	1.05
20.66	256	.3	20	1.27	18	0.71	17	0.78
20.66	256	.5	19	0.97	18	0.71	16	0.87
20.66	256	.7	20	0.99	19	0.69	20	1.57
20.66	256	.9	20	1.01	19	0.78	18	0.76
20.66	1,024	.1	18	1.30	18	0.97	18	1.12
20.66	1,024	.3	19	0.99	15	0.77	16	0.73
20.66	1,024	.5	18	1.21	16	0.67	19	0.95
20.66	1,024	.7	19	0.97	17	0.67	18	1.55
20.66	1,024	.9	19	0.81	19	0.79	17	0.82
23.84	4	.1	19	1.02	16	0.86	16	1.13
23.84	4	.3	19	1.12	20	0.75	20	1.14
23.84	4	.5	17	1.00	19	0.80	17	0.88
23.84	4	.7	20	1.26	16	0.79	18	0.80
23.84	4	.9	17	1.03	17	0.71	18	1.42
23.84	16	.1	18	1.22	16	0.96	16	1.19
23.84	16	.3	19	0.93	17	0.64	18	1.47
23.84	16	.5	20	1.02	19	0.66	18	1.10
23.84	16	.7	19	1.08	15	0.73	18	1.32
23.84	16	.9	19	1.20	20	0.98	17	0.85
23.84	64	.1	20	0.97	15	0.84	16	0.91
23.84	64	.3	19	1.23	18	0.85	17	1.29
23.84	64	.5	19	1.13	15	0.75	16	0.81
23.84	64	.7	20	0.96	18	0.72	17	0.87
23.84	64	.9	18	1.01	20	0.74	18	1.00
23.84	256	.1	16	1.34	19	1.00	15	1.20
23.84	256	.3	19	0.99	16	0.79	13	0.75
23.84	256	.5	16	0.94	18	0.71	17	0.75
23.84	256	.7	19	1.04	18	0.78	17	0.92
23.84	256	.9	19	1.04	17	0.71	18	0.80

Appendix B (Continued)

Minutes visual angle	Brightness	Contrast	Subject 1		Subject 2		Subject 3	
			Number correct responses	Average time per response	Number correct responses	Average time per response	Number correct responses	Average time per response
23.84	1,024	.1	18	0.85	18	0.70	18	1.04
23.84	1,024	.3	17	1.00	19	0.78	16	0.85
23.84	1,024	.5	20	1.04	15	0.71	17	0.75
23.84	1,024	.7	17	1.05	18	0.75	18	0.74
23.84	1,024	.9	20	0.94	16	0.72	19	1.07